PERGAMON

Renewable and Sustainable Energy Reviews
6 (2002) 249–272

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

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The role of renewable energy sources within the framework of the Kyoto Protocol: the case of Greece

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Abstract

The exploitation of Renewable Energy Sources (RES) forms an integral part of the effort to reduce the negative impacts from the use of fossil fuels and to confront the risks associated with climate change. The Kyoto Protocol (KP) sets legally binding commitments for developed countries with respect to their greenhouse gases emissions and, in that, represents the first step of a systematic effort for stabilization of greenhouse gases concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Taking into account that CO_2, originating almost exclusively from energy processes, is the most important greenhouse gas, the further development of RES forms an essential measure for the reduction of emissions. This paper examines whether the current development and planned actions in the field of the RES, even when straightforwardly associated with very ambitious targets for the present decade (e.g., the draft European Directive on the promotion of electricity from renewable energy sources in the internal electricity market), are sufficient in order to achieve the commitments according to the KP or more effort is needed in the direction of RES exploitation, combined with complementary actions such as energy conservation. © 2002 Elsevier Science Ltd. All rights reserved.

Contents

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PII: S1364-0321(01)00011-9

1. Introduction

1.1. The Kyoto Protocol targets and the role of Renewable Energy Sources

The worrying reports of the Intergovernmental Panel for Climate Change but also the weather itself lately have by now convinced even the more skeptical scientists and politicians that the world climate is changing and that anthropogenic emissions are one of the major contributors to this effect. The introduction of the Kyoto Protocol (KP) in 1997 represents an important attempt to put in place an effective international mechanism for the reduction of emissions of the six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6).

According to the agreed targets within the framework of the KP, total emissions of greenhouse gases (GHG) in developed countries during the first commitment period (2008–2012) must be reduced by at least 5% below 1990 levels. The European Union (EU) has agreed to a total reduction of its emissions by 8% below 1990. In 1998, the total GHG emissions at the EU amounted to 4.1 Gtn of CO_2 equivalent. CO_2 represents more than 80% of the total GHG emissions, while 95% of the total CO_2 emissions were generated from energy activities [1]. Therefore, it is clear that energy represents a key-sector in the effort for emissions reduction. Renewable

Energy Sources (RES) contribute virtually no GHG. Consequently their increased utilization in electricity generation and final energy uses should be a primary target in any national plan of action for meeting the KP GHG emissions reduction commitments.

In the present state of international negotiations, which seek to render the KP operational so that it can be ratified by Parties, there is no specific references in the various decisions under consideration, with respect to RES. Considering that, for the accomplishment of commitments according to KP, a substantial effort is required, the absence of any reference to RES does not form an integrated and strong intervention towards a high penetration of RES. However, it has to be investigated whether the KP itself, with the commitments that it foresees, may lead to a significant penetration of RES by 2010.

As it is clear that a significant effort will be required in order to fulfill the Kyoto commitments, several Member-States (MS) estimate that the accomplishment of their commitments within the KP framework is extremely difficult, if not impossible, without the introduction of Common and Coordinated Policies and Measures (CCPM) at EU level. By the June 1999 Decision of the Council of Ministers, the use of RES has been identified as one of the 12 CCPM to be pursued in the effort to meet its KP target. In October 1999, the Council of EU Environment Ministers decided the establishment of the European Climate Change Programme (ECCP), which encompasses activities in all sectors associated with climate change mitigation measures. According to the final report of the first phase of the ECCP [2], the reduction potential of GHG emissions from anticipated actions ranges from 1,120 Mt to 1,235 Mt CO_2-eq, of which the contribution of RES is estimated to be 25–30%.

To date, the only CCPM that has been formulated into a concrete policy is the promotion of renewable energy sources in electricity generation. Specifically, in the scope of the reorganization, integration and liberalization of the European energy market, a relevant EU Directive to establish new and ambitious national targets for RES utilization has been prepared [3] and is about to be finalized. According to this draft Directive, in 2010 the electricity produced by RES must cover 22% of total electricity production at the EU level, so that the target of the White Paper for a 12% share of RES in primary energy demand can be reached.

It should be mentioned that the promotion of RES has been adopted by the EU before the signing of the KP and has been incorporated in its research and energy programs (4th and 5th Framework Programme for Research and Development, SAVE, ALTENER etc.).

The simultaneous fulfillment of the KP and the RES targets especially in a liberalized market presents some interesting problems, which of course differ from MS to MS where the natural potential and existing degree of exploitation for RES varies substantially. Some MSs (notably Germany, Denmark and Sweden) have already in place ambitious national programs for the enhanced penetration of RES but still expect, as stated in their national action plans, to make as much use of RES as is feasible.

1.2. Estimations of RES penetration at the European and national level

At the EU level, the official projections on energy consumption are developed through the implementation of the PRIMES model [4,5]. According to the most recent official study of the European Commission [6], the contribution of RES in primary energy demand, according to certain scenarios formulated, is presented in Table 1.

According to the results of the PRIMES model, in the Baseline Scenario the participation of the RES in primary energy demand increases by 2010, but on the other hand the target of the White Paper on RES contribution in primary energy demand (12% for 2010 at the EU level) is not met. This occurs despite the substantial increase of solar and wind energy and is due mainly to the rather limited increase of biomass and hydro. The share of RES in primary energy demand increases in the case of scenarios imposing CO_2 emissions restrictions (scenarios S0, S3 and S6, in which CO_2 emissions in 2020 must be reduced by 0%, 3% and 6% below 1990 levels, respectively). However, even in these scenarios, the contribution of RES to primary energy demand in 2020 hardly exceeds 8%, regardless of the fact that RES exploitation is increased by 21% compared to the Baseline Scenario. In order to achieve

Table 1
RES in primary energy demand according to the PRIMES model (EU-15)

	Baseline scenario	Scenarios for CO_2 emissions reduction		
		S0	S3	S6
1990				
Primary energy demand (Mtoe)	1,314			
RES (Mtoe)	64			
% RES in primary energy demand	4.9%			
CO_2 emissions (Mtn)	3,068			
2010				
Primary energy demand (Mtoe)	1,552	1,501	1,482	1,464
RES (Mtoe)	88	96	101	107
% RES in primary energy demand	5.7%	6.4%	6.8%	7.3%
CO_2 emissions(Mtn)	3,289	3,068	2,977	2,885
CO_2 emissions increase from 1990	+7.2%	0%	−3%	−6%
2020				
Primary energy demand (Mtoe)	1,609	1,553	1,532	1,511
RES (Mtoe)	100	117	122	127
% RES in primary energy demand	6.2%	7.6%	7.9%	8.4%
CO_2 emissions (Mtn)	3,500	3,068	2,977	2,885
CO_2 emissions increase from 1990	+14.1%	0%	−3%	−6%

a 12% share of RES in primary energy demand, a particularly significant decrease of the cost of technologies for RES exploitation is required, that will render RES fully competitive to conventional energy technologies. Furthermore, it should be noted that reducing CO_2 emissions in the EU by 6% below 1990 levels in the most economically efficient way might not necessarily imply a high contribution of RES in primary energy demand.

The TERES II study represents another significant source of reference with respect to the prospect of RES penetration in the energy sector [7]. This study was elaborated before the introduction of the KP and therefore includes no reference to the commitments that the latter imposes. Furthermore, energy conservation issues were not incorporated in the analysis carried out in TERES II (i.e., primary energy demand is the same throughout all scenarios), as the scope of the study was the examination of different scenarios on RES penetration in the light of specific relevant supportive policies.[1] The energy model used for the elaboration of this study was SAFIRE (Strategic Assessment Framework for the Implementation of Rational Energy), an engineering–economic bottom-up model designed for the assessment of first-order impacts of rational (i.e. renewable and non-renewable) energy technologies on a national regional or local level against a background of different policy instruments and scenario assumptions [8]. The share of RES in primary energy demand in the various scenarios examined is presented in Table 2.

In the BP scenario of TERES II, the EU target for a 12% share of RES in primary energy demand by 2010 is met. As Tables 1 and 2 indicate, there are not any significant differences between the Baseline Scenario of PRIMES and the four scenarios of TERES II with respect to primary energy demand. However, in TERES II, RES exploitation is by 21–27% higher for the period 2010–2020 in the PP scenario (PP can be considered as the “equivalent” to the Baseline Scenario of PRIMES). The difference between the remaining scenarios of the two studies is even larger: while in PRIMES, RES reach at most 107 Mtoe and 127 Mtoe at 2010 and 2020 respectively, in TERES II the relevant figures are almost double, i.e. 197 Mtoe and 227 Mtoe for the same years. The exploitation of the various RES, according to the results of the two studies, is presented in Table 3.

Factors which explain, inter alia, the significant difference between these projections are:

- In PRIMES, the price of crude oil varies from \$17/bbl in 1995 to \$18/bbl in 2010

[1] **Present Policies (PP)**: Continuation of the implementation of present national policies. Subsidies for energy plantations within the framework of the Common Agricultural Policy are provided up to 2005.
Industrial Policies (IP): The proposals of trade–industrial associations, being active in the field of RES exploitation, are applied at EU level.

ExternE Internalisation (EI): The external cost per energy form and use, as estimated in the ExternE project, is introduced through the introduction of a relevant energy tax.

Best Practice Policies (BP): Best Practice Policies, resulting from the experience gained in individual countries, are applied to all countries (i.e., internalisation of external cost, support in the development of the relevant market, support for research and development).

Table 2
RES penetration in primary energy demand according to TERES II (EU-15)

	PP	IP	EI	BP
1993				
Primary energy demand (Mtoe)		1,366		
RES (Mtoe)		69		
% RES in primary energy demand		5.06%		
2010				
Primary energy demand (Mtoe)		1,571		
RES (Mtoe)	112	155	158	197
% RES in primary energy demand	7.1%	9.8%	10.1%	12.5%
2020				
Primary energy demand (Mtoe)		1,638		
RES (Mtoe)	121	186	190	227
% RES in primary energy demand	7.4%	11.4%	11.6%	13.9%

Table 3
RES in primary energy demand in 2020 — PRIMES and TERES II (EU-15)

RES	PRIMES (Mtoe)				TERES II (Mtoe)			
	Base-line	S0	S3	S6	PP	IP	EI	BP
Hydro	28.7	28.4	28.3	28.4	29.2	33.3	30.5	30.7
Wind	10.5	15.5	16.1	17.0	3.4	8.3	10.0	9.1
Solar	0.9	1.0	1.0	1.0	1.0	3.3	8.5	12.0
Biomass-waste	56.6	69.3	72.5	76.1	75.7	122.0	123.1	134.8
Geothermal	3.0	2.9	3.4	3.9	9.1	9.4	13.7	17.0
Biofuels	–	–	–	–	2.2	9.8	3.9	22.5
Other RES	–	–	–	–	0.05	0.0	0.1	1.0
TOTAL	99.7	117.1	121.3	126.4	120.8	186.3	189.9	227.2

and \$21/bbl in 2020. In TERES II, the price of crude oil is \$30/bbl in 2010 and \$32/bbl in 2020 (\$1998 values), a fact that implies that RES are more competitive in TERES II than in PRIMES.

- In PRIMES, the final contribution of RES results from the minimization of the overall system cost. Therefore, according to the assumptions made on the evolution of fossil fuels prices, as well as on the cost of RES, the minimum system cost does not imply a high penetration of RES, even in the case where a restriction for CO_2 emissions reduction by 6% below 1990 levels is imposed. In TERES II, concrete relevant policies for each scenario are defined. The selection of particular policies affects the values of certain parameters (discount rate, curve of RES penetration, taxes and incentives, environmental parameters) and implies specific changes regarding the cost and energy efficiency of RES. The different methodol-

ogical approach in the two studies, in combination with the assumptions made on the cost of RES, affects the final results.

- As regards biomass, for which major differences between the two approaches are detected, two of the scenarios in TERES II (IP, BP) include subsidies for O&M cost, promotion of cogeneration, recycling and consequent reduction of wastes to be disposed of at landfills. In addition, they include supportive measures for energy plantations (subsidies in the IP scenario, larger available area in the BP scenario). Furthermore, the use of biofuels is significantly promoted through exclusion of biofuels from excise duties. In the EI scenario, biomass and biofuels are also highly promoted, due to the fact that their external cost is much lower than that of conventional energy forms.

1.3. The Kyoto Protocol and RES as regards Greece

Within the burden-sharing agreement inside the EU, Greece must restrict the increase of its total GHG emissions to +25% between 2008–2012 and the base year (1990 for CO_2, CH_4, N_2O and 1995 for HFCs, PFCs and SF_6). Total GHG emissions for Greece in 1998 were 0.124 Gtn as compared its base year emissions of 0.105 Gtn of CO_2 equivalent. The relative weight of CO_2 in total GHG emissions, as well as the contribution of energy processes to CO_2 emissions, were similar to those at EU level: CO_2 represents 81% of total GHG emissions, while the energy sector is responsible for 91% of total CO_2 emissions [9].

At that same year (1998), RES contributed 5% of its primary energy consumption and 8% to electricity production including large hydro. Estimates of RES potential reaches 4.8 Mtoe, which represent 18% of present (1998) primary energy consumption and 25% of present (1998) electricity production. According to indicative targets proposed in this draft Directive for the various EU Member-States for the year 2010, electricity from RES in Greece should reach 20% of total electricity production.

The remainder of this paper is organised as follows. Section 2 discusses in more details the present status of RES exploitation in Greece in relation to the commitments undertaken within the UNFCCC and the available projections of their future penetration up to 2010. Section 3 presents the main assumptions for the development of four alternative scenarios under different policy targets and focuses on the results obtained regarding the penetration of RES achieved. Finally, in Section 4 the main findings of the study are summarised and conclusions are drawn.

2. Present and future penetration of RES in Greece

In the 1st National Action Plan (NAP) for the reduction of GHG emissions up to the year 2000 [10], the realistic potential for CO_2 emissions reduction from measures related to RES exploitation was estimated to approximately 2,300 kt CO_2 (almost 24% of the total emissions reduction potential, in order to achieve the target of limiting emissions' increase to +15±3% between 1990 and 2000). Measures with the largest expected potential were the promotion of wind energy (700 kt CO_2 avoided),

conventional solar systems (657 kt CO_2 avoided) and biomass for electricity generation (525 kt CO_2 avoided).

Taking into consideration the present penetration rate of conventional solar systems, as well as the investments in RES already approved and/or implemented within the existing legal framework, the avoided CO_2 emissions from measures in the field of RES are estimated to approximately 2,600 kt CO_2. This indicates that the expected emissions reduction from measures related to RES will be achieved, even with some delay. However, the figures related to the evolution of total CO_2 emissions in Greece during recent years indicate that the measures for the promotion of RES were not sufficient to limit CO_2 emissions to the levels set in the 1st NAP.

Specifically, total GHG emissions in 1998 were 0.124 Gtn of CO_2 equivalent [9]. Compared to 1990, CO_2 emissions increased by 18%. Therefore, the upper limit for the emissions' increase by the year 2000, according to the commitments of the 1st National Action Plan, was reached already in 1998. Furthermore, the average annual rate of increase of emissions from 1996 and onwards is particularly high (+3%, compared to +1% for the period 1990–1995). This tendency is due mainly to the increase of electricity demand, as well as of energy consumption in transport. These sectors were responsible for 74% of the total CO_2 emissions in 1998.

The projections of PRIMES and TERES II on RES penetration in Greece are shown in Table 4. The total penetration of RES is estimated at 1.7 Mtoe by PRIMES (baseline scenario) and at 2.5 Mtoe by TERES II (PP scenario). There are small differences in the projected exploitation of hydro, solar and wind energy between the two studies, with the PRIMES being more optimistic regarding the penetration of wind and solar energy. The main source of variation in the projections is related

Table 4
RES in primary energy demand — PRIMES and TERES II (Greece)

RES	PRIMES — Baseline (Mtoe)[a]		TERES II(Mtoe)							
	2010	2020	2010				2020			
			PP	IP	EI	BP	PP	IP	EI	BP
Hydro	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Wind	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Solar	0.2	0.3	0.1	0.2	0.2	0.3	0.1	0.2	0.5	0.4
Biomass-waste	0.9	1.0	1.7	3.4	3.5	2.6	2.0	3.8	3.9	4.1
Geothermal	–	–	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2
Biofuels	–	–	0.01	0.1	0.04	0.3	0.04	0.2	0.1	0.6
TOTAL	1.7	2.1	2.5	4.2	4.5	4.8	2.8	4.8	5.3	6.0
Primary energy demand	35.8	40.5				28.9				32.0
% RES in primary energy demand	4.9	5.3	8.5	14.7	15.7	17.1	8.8	15.1	16.5	17.6

[a] In the Baseline scenario of PRIMES, CO_2 emissions increased by 54% between 1990 and 2010.

to biomass exploitation, for which the TERES II study estimates a consumption of 1.7 Mtoe (0.9 Mtoe in PRIMES). Moreover, the use of biofuels (0.01 Mtoe) and of geothermal energy (0.1 Mtoe) is projected only by TERES II. Furthermore, it should be noted that the primary energy demand predicted in the Baseline Scenario of PRIMES for Greece, primary energy demand is significantly higher than that one predicted in TERES II. As a result, the above-mentioned factors lead to a higher share of RES in primary energy demand according to TERES II.

The present emission inventory data and energy consumption figures, combined with the differences between the estimations of PRIMES and of TERES II for the share of RES in the energy balance for 2010, lead to the following questions, which are examined in the present paper:

1. What is the effect of pursuing the RES target set by the Proposed Directive on the GHG emissions towards meeting the KP target and at what cost?
2. What is the optimal RES penetration on economic terms under the constraint that the KP target is met?

In order to investigate the previously mentioned policy questions, a model of the Greek energy system was developed and simulations were carried out with the assistance of ENPEP/BALANCE, a tool for energy planning developed and supported in USA by the Argonne National Laboratory, following an initiative of the USA Department of Energy in 1984. This widely used simulation tool allows for the development of a bottom-up model, while energy supply and energy demand are represented through a set of non-linear equations.

BALANCE is used to trace the flow of energy throughout the entire energy system from resource extraction, through processing and conversion, to meet demands for useful energy (e.g. heating, transportation, electrical appliances) and employs a market-based simulation approach to project future energy supply/demand balances. For its simulation, the model uses an energy network that is designed to trace the flow of energy from primary resources through to final energy. A fundamental assumption of the model is that producers and consumers both respond to changes in price. Furthermore, energy demand is sensitive to the prices of alternatives, as supply price is sensitive to the quantity demanded. ENPEP seeks to find, except the intersection of the supply and demand curves, the intersection for all energy supply forms and all energy uses that are included in the energy network. The equilibrium is reached when the model finds a set of prices and quantities that satisfy all relevant equations and restrictions. As market shares of energy are dependent on energy prices and energy prices are dependent on the quantity of fuel demands, ENPEP uses an iterative process to bring network prices and quantities into equilibrium.

3. Results

To try to provide answers to the questions stated above, four main scenarios have been formulated. The first one, Business as Usual Scenario, is expected to provide

the baseline with which to gauge the results of the other scenarios. It incorporates all the basic assumptions that one considers appropriate, most of which will also be incorporated in the other three scenarios. The second and third scenarios insist that the RES targets set by the Proposed Directive are met, while at the same time GDP is maintained at the BaU levels and no effort is made to further decouple energy use with GDP growth. The fourth scenario represents the feasible on economic terms way to meet the commitments undertaken by Greece under the KP maintaining GDP at the BaU levels.

3.1. Business as usual (BaU) scenario

3.1.1. Main assumptions

The first step in estimating the cost for GHG emissions reduction is the formulation of a Business as Usual (BaU) scenario, which estimates the evolution of emissions when no additional reduction policies are adopted. This scenario affects significantly the final results, as the higher the estimated emissions in this scenario are, the higher is the need for emissions reduction in order to fulfill the national commitments. At the same time, however, high emissions in the BaU scenario may indicate the existence of low-cost policies and measures for GHG emissions reduction.

The level of emissions estimated in the BaU scenario depends on assumptions regarding the main parameters, such as population, economic growth, energy prices, etc. It also depends on which are the specific reduction policies incorporated into the scenario. In this study, carried out with the aid of a bottom-up model of the Greek energy system based on ENPEP/BALANCE, the projections in the BaU scenario cover a planning horizon up to the year 2010 (i.e., the middle point of the first commitment period 2008–2012). The main assumptions made for the projection of energy consumption and associated CO_2 emissions in the BaU scenario were:

3.1.1.1. Demographic characteristics The average annual rate of growth of population during the period 1990–2010 was estimated to be 0.25%, following the projections made by the National Statistical Service [11], while the household size is assumed to decrease by approximately 0.7% for the same time period. Therefore, the total number of households presents an annual increase at a rate of 1% for the period 1990–2010 and an overall increase by 20% during the entire time period. The evolution of population and households represents a crucial parameter for the results obtained, as it defines to a large extent the energy needs in the residential and in the tertiary sector, as well as in the transport sector.

3.1.1.2. Weather conditions Future weather conditions were assumed to remain the same as those in recent years [6]. Assuming that weather conditions will be closer to the historical average would ignore the fact that the average annual temperature has already increased noticeably in the last decade, and consequently the use of the lower historical average temperature would lead to a sudden, non-justifiable increase of space heating requirements after the year 2000. If future weather con-

ditions turn out to be closer to the historical average, then the energy consumption (primary and final) would be different from the one predicted in this paper.

3.1.1.3. Macro-economic parameters For the estimation of GDP, the OECD short-term predictions (up to the year 2002) were used [12], while for the period up to 2010 the rates estimated in [6] were applied. The average annual rate of growth for the period 1990–2010 is estimated to be approximately 3%. The sector of services shows the highest annual rate of growth (3.8%), while its share in GDP in 2010 is estimated at 77% (65% in 1990). The annual rate of increase in industry is approximately 1% and its contribution to the total GDP decreases from 27% in 1990 to 18% in 2010. The annual rate of growth in the primary sector is 0.7% (its contribution decreases from 8% in 1990 to 5% in 2010).

3.1.1.4. Energy prices/taxes Fuel prices depend on the conditions in the international oil, natural gas and coal markets, as well as on national pricing policies. As the majority of analyses indicate that international oil prices will not present sharp fluctuations, it was assumed that the relevant fuel prices would remain at 1997 levels. Following this assumption, the basic characteristics of the present fuel taxation policy will not change and a carbon tax on fuel prices will not be introduced during the planning period examined. It should be noted that in relevant discussions at EU level, the Greek government opposed the introduction of a similar tax, at least in the short-term although that may change toward the end of the current decade.

3.1.1.5. Policies and measures BaU defines the future development of the energy system under current policies and consumers' behavior, as well as under the emerging future trends. Specifically, the BaU scenario comprises:

- Liberalization of local electricity market.
- Agreement between the EU and car industries (ACEA, KAMA, JAMA) regarding the decrease of fuel consumption in new cars, with the aim to achieve an average CO_2 emission factor of 140 gr/km by 2008 (with an intermediate target of 170 gr/km by 2003).
- Continuation of present policies for the promotion of RES, cogeneration and energy conservation.
- Integration of the expected GHG emissions reductions from projects in the field of RES and energy conservation, which have been approved within the Operational Programme for Energy (financed by 2nd Community Support Framework).

3.1.2. Results obtained

3.1.2.1. Primary energy consumption Primary energy consumption increases continuously during the entire time period (from 22.5 Mtoe in 1990 to 32.5 Mtoe in 2010), at an average rate of increase around 2% (Fig. 1). Liquid fuels cover the major part of primary energy consumption. However, their contribution decreases from 60% in 1990 to 55% in 2010. The consumption of solid fuels shows an increase in the order of 12% during 1990–2010, while their share falls from 36% in 1990

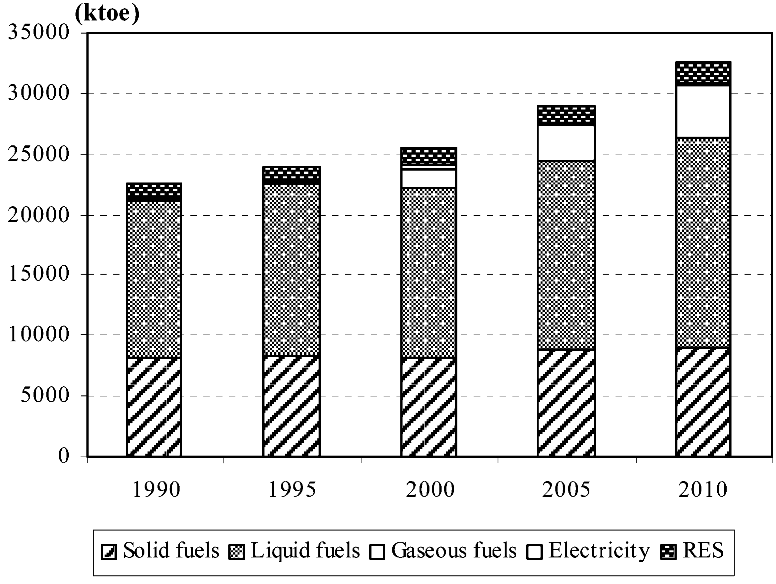

Fig. 1. Primary energy consumption in the BaU scenario.

(8,000 ktoe approximately) to 28% in 2010 (9,000 ktoe approximately). Natural gas covers 13.5% of primary energy consumption in 2010 and its penetration results in a decrease of the relative contribution of solid and liquid fuels. The share of RES including large hydro in primary energy consumption for the entire period examined is in the range of 5% (1,600 ktoe in 2010). In absolute values, their exploitation increases by 45% from 1990 to 2010. The low RES share in primary energy consumption, despite the incorporation of relevant investments into the BaU scenario, is due mainly to the decrease of biomass consumption for space heating purposes in the residential sector, a result of improved living standards and subsequent shift of consumers towards other space heating systems.

The predicted share of RES in primary energy consumption in the BaU scenario (5% in 2010) is very close to the projections of the Baseline Scenario of the PRIMES model and significantly lower from the estimations of TERES II (Table 4). Compared to the BaU scenario, the Baseline Scenario of PRIMES predicts a 0.1 Mtoe higher contribution of RES in primary energy consumption, which, however, when combined with the higher total primary energy consumption that is predicted by PRIMES, leads to a similar RES share. The difference regarding RES exploitation is due to the higher penetration of wind energy in PRIMES. The significantly lower RES penetration in the BaU scenario, compared to the Present Policies/PP scenario of TERES II, is due to the fact that the BaU scenario implies lower biomass consumption by 2010. Specifically, biomass consumption increases from 0.87 Mtoe in 1990 to 0.91 Mtoe in 2010 in the BaU scenario, as opposed to 1.1 Mtoe (1993) to 1.7 Mtoe in TERES II. This difference is due mainly to the fact that RES technologies in TERES II include the exploitation of urban and industrial wastes for electricity and

heat production, as well as the development of energy plantations for heat production, technologies that have not been incorporated in the BaU scenario.

3.1.2.2. Electricity production The introduction of natural gas in electricity generation, together with the liberalization of the electricity market, represent major structural developments incorporated in BaU. The liberalization of the market is simulated through the definition of three categories of producers, which are differentiated regarding their economic characteristics and the needs that they cover, i.e.,

- Large electric utilities
- Industrial auto-producers using natural gas
- Independent producers in the industrial and tertiary sectors, covering their needs in heat and electricity through cogeneration with natural gas.

Natural gas power plants operated by large electric utilities cover approximately 20% of the total electricity production in 2010 (1,055 ktoe), thus reducing the relevant participation of lignite from 70% to 50% during the period 1990–2010. However, in absolute values, the electricity produced from lignite power plants increases by 30%. Industrial auto-producers cover 5% of the total electricity produced (260 ktoe), while the share of cogeneration is approximately 1%. In total, the use of natural gas for electricity production corresponds to 25% of the electricity produced (Fig. 2). The share of oil power plants in electricity production is reduced to 15% in 2010 (810 ktoe), while the contribution of RES (large hydro included) increases from 6% in 1990 to 9.5% in 2010 (530 ktoe). Wind energy covers approximately 1.5% of

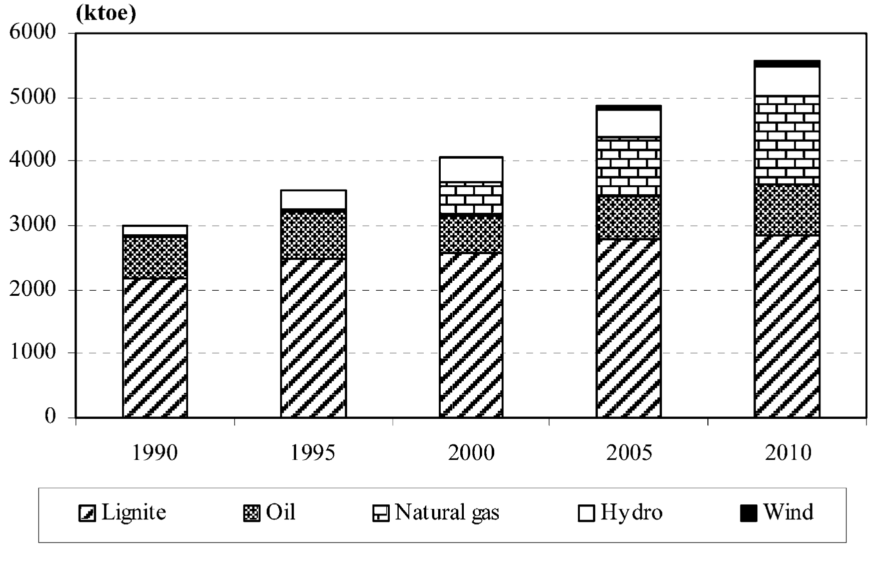

Fig. 2. Electricity production in the BaU scenario.

the total electricity produced in 2010 (90 ktoe), with an installed capacity around 400 MW.

3.1.2.3. Final energy consumption Final energy consumption increases continuously during the entire time period (from 14.6 Mtoe in 1990 to 23.2 Mtoe in 2010), with an average rate of growth in the order of 2.5% (Fig. 3). Liquid fuels have the highest share in primary energy consumption, presenting however a slight decrease of their contribution from 68% in 1990 to 64% in 2010. Electricity consumption shows an annual increase at a rate of 3.2%, while its contribution to final energy consumption increases from 17.5% in 1990 (2,550 ktoe) to 20.5% in 2010 (4,750 ktoe). Natural gas represents approximately 7.5% of final energy consumption in 2010 (1,705 ktoe). This penetration results in a decrease of the relevant contribution of liquid fuels and the limitation of the electricity growth rate. The share of RES

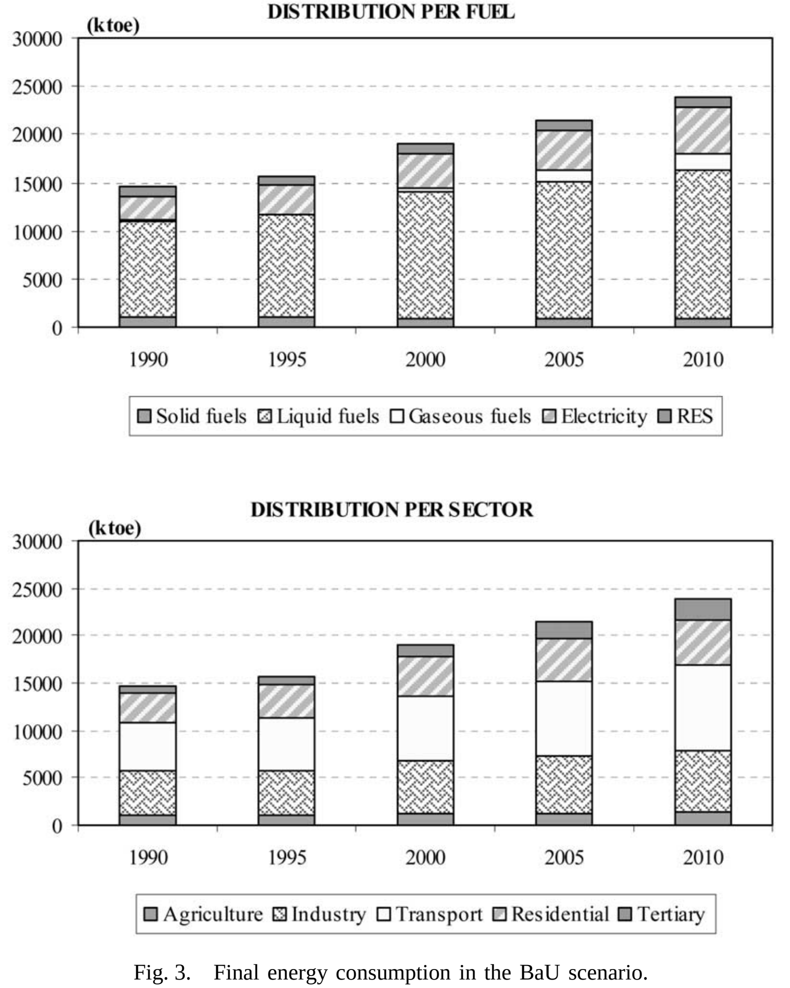

Fig. 3. Final energy consumption in the BaU scenario.

decreases from 6.5% in 1990 to 4.7% in 2010, while in absolute values their exploitation increases by 15% in 1990–2010. The reduction of the RES share in final energy consumption, despite the significant penetration of solar systems, is due as is the case with primary energy production mainly to the reduced biomass consumption in the residential sector.

The structure of final energy consumption per sector (Fig. 3) is in line with the characteristics of the economic development. The share of industry and primary sector in final energy consumption is reduced (from 32% in 1990 to 25% in 2010 and from 7.5% to 6.5%, respectively). The contribution of tertiary and transport sectors increases by 5 and 4 percentage units, respectively. The share of the residential sector in the final energy consumption remains stable around 20%, due to the penetration of natural gas, and the use of electric devices and central heating installations with higher energy efficiency.

3.1.2.4. Carbon dioxide emissions The BaU scenario leads to an increase of CO_2 energy sector emissions by 44% between 1990 and 2010 (annual rate of increase in the order of 2%). In total, the rate of increase of emissions is slowed down, mainly because of the penetration of natural gas: from 3.5% during the period 1995–1998, it decreases to 2.3% during 2000–2005 and to 1.7% during 2005–2010. The emissions from international air and aviation (bunkers) are not included in these figures, as to date these emissions are not included in national totals to be used for compliance purposes.

3.1.3. Overall assessment of the energy system in BaU

The basic parameters, which affect the future structure of the Greek energy system, are: (a) the rate of economic growth, (b) the shift of the economic activity towards services, (c) the penetration of natural gas, and (d) the liberalization of the local electricity market.

Following the high rate of economic growth and the improvement of living standards, primary and final energy consumption per capita presents a consecutive increasing trend. However, economic growth does not lead to a proportional increase of energy consumption and carbon dioxide emissions, due to the improvement of the total energy efficiency of the system as a result of the substitution of liquid and solid fuels by natural gas. Therefore, the energy intensity of the Greek energy system (i.e., primary energy consumption per unit GDP), as well as the intensity of carbon dioxide emissions (i.e., carbon dioxide emissions per unit GDP) is improved by 20%. As a further consequence of the introduction of natural gas into the Greek energy system, carbon dioxide emissions per unit of primary energy consumption decrease continuously from 2000 and onwards, approaching the levels of 1990 in 2010 (Fig. 4).

3.2. Impacts on CO_2 emissions from the implementation of the draft EU directive on the promotion of RES in electricity generation

In Article 2 of the KP, the need for the establishment of Common and Coordinated Policies and Measures (CCPM) in order to reduce greenhouse gases emission is

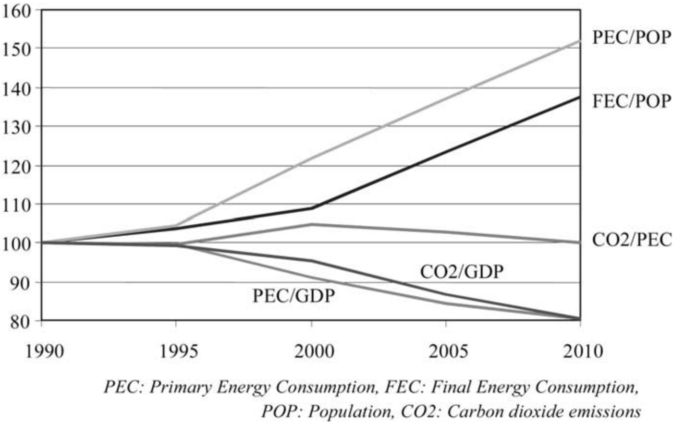

Fig. 4. Evolution of basic indices of the Greek energy system in the BaU scenario.

mentioned. Toward this end, in 1997, the European Commission defined twelve categories of such policies and initiated relevant work papers. The draft Directive on the promotion of electricity from RES in the internal electricity market [3] constitutes a first coordinated effort, aiming at duplicating the share of RES in energy needs from 6% to 12% at the EU level. For the fulfillment of this target, the Directive foresees the implementation of appropriate actions in the various Member-States, in order to increase the RES share in electricity generation. At the same time, it sets a specific percentage-target for the EU as a total, while setting indicative percentage-targets for each Member-State. The electricity production from RES (including large hydro) in 2010 must cover 22.1% of the total electricity produced in the EU, compared to 13.9% in 1997. For Greece, the indicative target refers to a significant increase of the RES contribution in electricity generation (from 8.6% in 1997 to 20.1% in 2010 including large hydro, or from 0.4% in 1997 to 14.5% in 2010 without large hydro).

It is clear that the implementation of such targets for RES penetration will induce great reductions in GHG emissions, but will also imply substantial modifications to the existing electricity generation systems of the various Member-States. In Greece, according to the results of the BaU scenario, electricity generated by RES during the period 1995–2010 is expected to cover 8.6–9.7% of total electricity production, with an estimated share of 9.5% in 2010. The fulfillment of the above mentioned target for RES penetration (i.e., 20.1%) will require the undertaking of a significant number of investments and a radical change in the present investors' behavior, who to date have been mainly interested in investments for natural gas power plants. In this study, the reduction potential of energy consumption and CO_2 emissions under two alternative scenarios for the achievement of the penetration target for RES, as proposed in the draft Directive, were estimated. These scenarios are:

- Scenario 1 (DS1): New RES installations, required for the fulfillment of the national target proposed in the draft Directive, are developed "at the expense" of

other new electricity generation units that are going to be constructed in order to satisfy the electricity demand.

- Scenario 2 (DS2): New RES installations replace old lignite and highly polluting oil power plants, as well as new plants that were to use fossil fuels and were to be constructed during the planning period in order to satisfy the electricity demand.

The total installed capacity of RES power plants estimated as necessary for achieving the target set by the proposed Directive, in 2010 was 2,400 MW for wind systems, 500 MW for small hydro and 80 MW for biomass installations. The estimated energy conservation, as well as the expected CO_2 emissions reduction for these two scenarios is presented in Table 5, while the emissions reduction achieved per sector of economic activity (by distributing the CO_2 emissions from electricity generation to the other activity sectors according to their relative consumption of electricity), compared to the BaU scenario, is presented in Fig. 5. Specifically, under the DS1 scenario, the total energy conservation is estimated to be 1.7 Mtoe, while CO_2 emissions reduction is 4.7 Mt, contributing by 24% to the total national effort for the fulfillment of the KP commitments. The marginal cost of this enhanced penetration is \$62/ton CO_2 (Fig. 6). Under the DS2 scenario, the total energy conservation is estimated to be 1.9 Mtoe, while CO_2 emissions reduction is 7.2 Mt, increasing the respective contribution in the entire national effort to 38%. The marginal cost of this enhanced penetration is \$67/ton CO_2 (Fig. 6). In both scenarios, the share of RES in primary energy consumption is approximately 7.5%.

These results indicate that although the achievement of the target for RES set in the draft Directive will contribute substantially to CO_2 emissions reduction, nevertheless it cannot lead by itself to the fulfillment of national commitments according to the KP. In order to be in compliance with these commitments, significant additional interventions are required, in final energy demand as well as in energy supply or even in other non-energy related sectors. The issue which arises at this point, and which is explored in the next paragraph, is which is the best combination between RES exploitation (in electricity generation as well as in final energy consumption)

Table 5
Fuel conservation and CO_2 emissions reduction in 2010 for Greece, resulting from RES penetration in electricity generation according to the draft EU Directive and the SEE

Fuel	Scenario 1 (DS1)		Scenario 2 (DS2)		Scenario 3 (SEE)	
	Fuels conservation (ktoe)	Emissions reduction (Mt CO_2)	Fuels conservation (ktoe)	Emissions reduction (Mt CO_2)	Fuels conservation (ktoe)	Emissions reduction (Mt CO_2)
Lignite	–	–	820	4.2	3,365	14.7
Heavy fuel oil	525	1.7	500	1.6	465	1.3
Diesel	360	1.1	120	0.4	–	–
Natural gas	810	1.9	440	1	−217	−0.1
Total	1,695	4.7	1,880	7.2	3,613	15.9

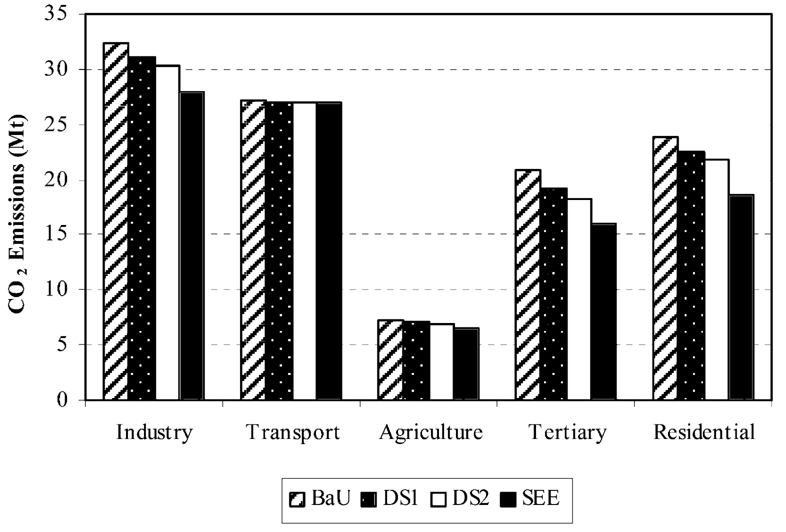

Fig. 5. CO_2 emissions reductions per sector under the scenarios investigated for Greece.

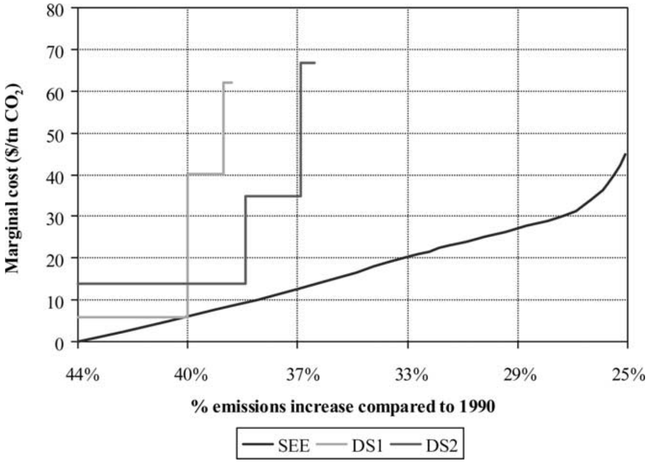

Fig. 6. Marginal cost curve for CO_2 emissions reduction in Greece.

and additional actions, so that national commitments for GHG emissions reduction are fulfilled according to the maximum possible cost effectiveness.

3.3. CO_2 emissions reduction under the objective of economic efficiency

Under the assumption of maintaining GDP at the levels of the BaU scenario, the fulfillment of national commitments with respect to emissions reduction is expected to lead in increased energy system's expenses: emission reductions below a specific

level require the implementation of energy conservation policies, the use of cleaner fuels and the adoption of more efficient technologies, actions that are usually characterized by an increased cost.

The marginal cost and the structural changes in the different economic sectors of the Greek energy system, as a result of the implementation of policies for the fulfillment of the KP commitments, were explored with the assistance of the ENPEP/BALANCE tool. As already mentioned, these commitments consist in restricting the increase of GHG emissions to +25% in 2008–2012 compared to 1990 levels. It is noted that in the Scenario of Economic Efficiency (SEE), which has been formulated and presented below, emphasis was given to CO_2 emissions from the energy sector, as the latter represent the major part of GHG emissions. The emissions of the other greenhouse gases, as well as the emissions from the non-energy sector, were not included in the analysis.

According to the results obtained, the marginal cost for the limitation of the increase of CO_2 emissions at +25% in 2010 compared to 1990 levels is estimated to be \$45/t CO_2 (1997 prices). As shown in Fig. 6, the cost for CO_2 emissions reduction increases almost linearly up to a certain point. From this point onwards, cost increases disproportionally to the achieved emissions reduction: the limitation of the increase of emissions to +29% implies a cost in the order of \$27/t CO_2, while for the accomplishment of the +25% target, the cost increases sharply to \$45/t CO_2. A more detailed study (compared to [2]) by PRIMES focusing in the case of Greece estimates a cost of \$50/t CO_2 (1997 prices) [13].

However, it should be noted that this estimate is only based on the analysis of CO_2 emissions from the energy sector. Therefore, there could be cost effective measures concerning the non-energy sectors and/or non-CO_2 gases, the implementation of which could prevent this sharp increase of cost from \$27/t CO_2 to \$45/t CO_2. Moreover, the flexible mechanisms of the KP could represent a cost-effective option for the reduction of CO_2 emissions. If, for instance, the price set for the emissions trading mechanism is around \$30/t CO_2, then the limitation of the increase of emissions from +29% to +25% (i.e. 3.1 Mt CO_2) can be achieved at a significantly lower cost.

The most important impacts in the energy system's structure that the implementation of such a policy induce are the reduction of solid fuels and electricity consumption, the increase of natural gas consumption and RES exploitation, and the undertaking of actions in end-use sectors towards a rational and efficient energy use. Specifically, the most significant modifications that the SEE imposes, compared to the BaU scenario, regarding energy supply are: (a) the decrease of solid fuels consumption (from approximately 9,000 ktoe to 6,100 ktoe), (b) the increase of natural gas penetration (from 4,400 ktoe to 4,700 ktoe for the year 2010) and, (c) the higher share of RES, which reaches 2,240 ktoe in 2010, contributing by 7.5% in primary energy consumption. However, this figure is lower than the one in TERES II, even for the most conservative scenario (Present Policies/PP), by one percentage unit. The implementation of SEE leads to an increase of the RES contribution to primary energy consumption by 49%, compared to the BaU scenario (Fig. 7).

As already mentioned, the share of RES in primary energy consumption estimated in the scenarios for the fulfillment of the indicative target set by the draft Directive

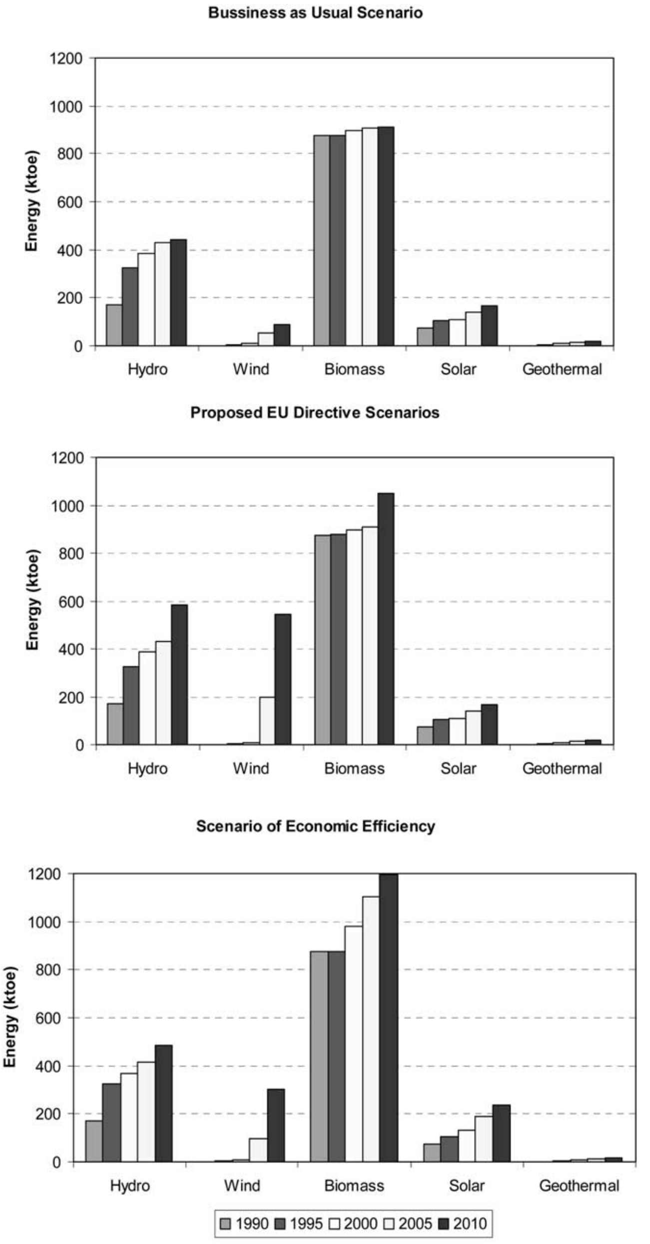

Fig. 7. Contribution of RES in primary energy under the scenarios investigated for Greece.

on the promotion of RES in electricity generation is also in the order of 7.5%. However, these scenarios do not, as such, lead to the fulfillment of national commitments within the KP framework. The higher primary energy consumption in these scenarios, compared to the relevant one in the SEE (by approximately 5%), and the higher rate of increase of electricity consumption (3.2%, compared with 2.4% in SEE) represent the most important characteristics of these scenarios. Additionally, scenarios DS1 and DS2 favour the penetration of the most mature technologies for electricity generation (hydro and wind energy), while in SEE there is a more balanced contribution from all RES (Fig. 7).

With respect to electricity generation, the implementation of SEE leads to significant modifications in the national power system (Tables 5 and 6). At first, a large-scale exploitation of wind energy is favored, generating 305 ktoe of electricity (total capacity of 1,350 MW) in 2010. In addition, there is a significant exploitation of hydro potential, mainly through the construction of small plants, with a total capacity of 400 MW. The total contribution of RES in electricity generation reaches 16.7% of the total electricity produced in 2010 (percentage significantly higher than the 9.5% estimated in the BaU scenario, but significantly lower than the 20.1% foreseen in the draft Directive for RES). In addition, the implementation of SEE favours a high penetration of natural gas (as in the case of BaU) in electricity generation, encouraging, however, more large consumers of the industrial and tertiary sectors in implementing relevant investments. Finally, the higher CO_2 emission factor of lignite leads to a lower exploitation of lignite power plants, as well as to the retirement of some old and highly polluting units. The total CO_2 emissions from electricity generation decrease substantially not only compared to BaU (from 56.2 Mt in BaU to 40.3 Mt in SEE in 2010), but also to DS1 (51.5 Mt in 2010) and DS2 (49 Mt in 2010). This results mainly from the radical decrease of electricity demand (from 5.2 Mtoe to 4.4 Mtoe), as well as from the use of cleaner energy forms in electricity production.

At the level of final energy demand, the application of SEE induces the following modifications compared to the BaU scenario:

Table 6
Electricity production (in ktoe) under the various scenarios investigated for Greece

Type of unit	Electricity Production in 2000		Electricity Production in 2005				Electricity Production in 2010			
	BaU	SEE	BaU	DS1	DS2	SEE	BaU	DS1	DS2	SEE
Lignite	2,318	2,022	2,507	2,507	2,462	1,873	2,559	2,559	2,336	1,649
Oil	547	524	645	579	598	540	771	543	604	652
Natural gas	508	628	870	795	833	1,072	1,304	928	1,100	1,328
Hydro	387	369	430	460	460	418	431	585	585	485
Wind	7	7	53	196	196	96	87	543	543	304
Biomass	0	0	0	0	0	0	0	40	40	0
Total	3,767	3,550	4,505	4,537	4,549	3,998	5,151	5,198	5,208	4,418

- Industrial sector: the largest part of emissions reduction derives from the use of more energy efficient technologies, both in production and auxiliary processes. Furthermore, the exploitation of biomass and solar energy for thermal uses is promoted, while the consumption of solid and liquid fuels (heavy fuel oil) is limited.
- Transport: significant changes do not occur, since substantial technological developments were already incorporated in the BaU scenario. The use of natural gas in public transport is supported, as well as a further development of the electrified railroad network. However, only the introduction of strict limiting measures can lead to significant additional technological changes in this sector, which will lead to high CO_2 emissions reduction.
- Residential and tertiary sectors: the results from SEE indicate that a significant emission cuts are possible through the promotion of more efficient electric devices (with emphasis on air conditioning and lighting), as well as through improvements in space heating systems and in the thermal behavior of buildings. Fuel substitution offers also significant prospects for CO_2 emissions reductions, particularly through increased exploitation of solar energy in the residential sector and of natural gas in the tertiary sector.
- Agricultural sector: the most important changes that SEE induces are related mainly to space heating in greenhouses through the promotion of biomass and geothermal energy.

4. Conclusions

All developed countries have to undertake significant initiatives within the next decade in order to fulfill their commitments under the KP. This paper investigated which may be the role of RES in Greece towards this direction, compared to other existing recent studies.

At a first stage, the RES penetration in the Greek energy system was estimated on the basis of present policies and measures (BaU scenario), given the technological and other developments in the energy system and in the economic environment, through the assistance of the ENPEP/BALANCE tool for energy planning. According to the results obtained, the contribution of RES in primary energy consumption in 2010 is estimated to be 5%, a figure that is close to the most conservative estimations of other studies (e.g., the PRIMES model), while the total increase of CO_2 emissions from the energy sector during 1990–2010 is estimated to be +44%. It should be noted that given the available projections for a reduction in precipitation and the increased water demand, especially in the islands of Greece, desalination of seawater represents a promising option for significant RES penetration.

The implementation of the draft Directive for an increased exploitation of RES in electricity generation will certainly contribute to a higher RES penetration than to date. Thus, the total installed capacity of RES power plants was estimated to be 2,400 MW for wind systems, 500 MW for small hydro and 80 MW for biomass installations, while the share of RES to primary energy consumption (in 2010) is

approximately 7.5%. However, CO_2 emissions reductions anticipated through this policy are not sufficient for the accomplishment of national commitments under the KP, as the emissions reduction achieved leads to a restriction of the increase of CO_2 emissions of +38% for DS1 and of +35% for DS2 compared to 1990 levels.

Therefore, it is clear that planned interventions should not be limited to electricity generation, but must cover the various energy demand and supply sectors. A scenario for the fulfillment of KP commitments, formulated on the basis of economic efficiency, results in a 7.5% penetration of RES in primary energy consumption, a figure that is higher by 48% than that in BaU, but significantly lower than that in TERES II. Furthermore, the contribution of RES in electricity generation reaches 16.7% of the total electricity produced in 2010, a percentage that is significantly higher than the 9.5% estimated in BaU, but lower than the 20.1% foreseen in the Draft Directive for RES. At the same time, significant complementary actions must be undertaken, supporting the penetration of efficient energy technologies and the use of cleaner fuels.

Additionally, the estimated cost for the fulfillment of KP commitments on economic efficiency terms is significantly lower than the cost estimated for the scenarios implementing the Draft Directive, not only for the same level of emissions reduction, but also for being in compliance to the KP commitments. Moreover, the cost of \$45/t CO_2 can only be considered as indicative, since neither non-energy sectors/non-CO2 gases nor the use of the KP flexible mechanisms, were examined in this paper.

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